Quickdraw: The Impact of Mobility and On-Body Placement on Device Access Time

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ABSTRACT
We investigate the effect of placement and user mobility on the time required to access an on-body interface. In our study, a wrist-mounted system was significantly faster to access than a device stored in the pocket or mounted on the hip. In the latter two conditions, 78% of the time it took to access the device was spent retrieving the device from its holder. As mobile devices are beginning to include peripherals (for example, Bluetooth headsets and watches connected to a mobile phone stored in the pocket), these results may help guide interface designers with respect to distributing functions across the body between peripherals.

ACM Classification Keywords
H.5.2 User Interfaces: Evaluation/methodology; Input devices and strategies

INTRODUCTION AND RELATED WORK
Mobile phones have become ubiquitous, with the number of subscribers worldwide at more than three billion[1]. It is not uncommon for mobile phones to be the first object with which people interact in the morning and one of the last things with which people interact in the evening [1]. Despite the importance of these mobile devices in everyday life, little empirical data has been published on many fundamental usage properties.

Patel *et al.* examined people's perceptions about how often they have their mobile phone nearby. Their data show that people routinely overestimate the physical availability of their mobile phones [3]. Even when the mobile phone is with its user, it may not be quickly accessible; Cui *et al.* found that 40% of women and 30% of men miss phone calls simply due to the manner in which they carry the mobile phone on their person [2]. Similarly, Starner *et al.* found correlations between an individual's decision to use or not use a mobile scheduling device (such as a day planner or PDA) and the amount of time and effort required to access and make ready the device [4]. Together, these studies suggest that the time required to access a device may be an important property affecting mobile use.

Fortunately, miniaturization of mobile electronics allows the mobile interaction designer increasing freedom in distributing functionality between on-body peripherals with complementary properties. Already, Bluetooth wristwatches and ear-mounted headsets allow the user to monitor and interact with a phone stored in the pocket. Intuitively, such alternative mounting points may lead to lower access times.

In this work, we examine and quantify two important factors that could impact access time: on-body placement and user mobility. Specifically, we focus on the effects of walking versus standing when accessing a touch screen interface mounted on the wrist, on the hip, and in the pocket.

EXPERIMENT
To explore how body placement and mobility influence the time needed to respond to and access a mobile device, we examined two independent variables with a 2x3 Latin-square within-subjects study design. The first variable is the mobility of the participant and the second is the placement of a device on the body. Although our interest in mobile devices is broader than telephones, we used a mobile phone throughout the study in order to keep the interaction consistent between conditions.

Our two mobility conditions are standing and walking, chosen because people on-the-go are likely to be in one of these two states much of the time. Our three on-body placement conditions were in the pocket, on the hip in a holster, and on the wrist, reflecting common placements for current mobile electronics.

During the standing condition we instructed participants to stand in a corner of our lab to minimize visual distractions that might interfere with access time. For the walking condition, participants were instructed to walk at a normal pace around a track constructed in our laboratory (Figure 1). The track was approximately 26 meters long and was denoted with flags hanging from the ceiling with the tips 0.75 meters apart. Each flag was hung so the tip was approximately 1.6 meters above the floor. We chose to use this flag arrangement rather than floor-based track markers (as in [5])

[1] `http://www.portioresearch.com/WWMM_stats07.html`

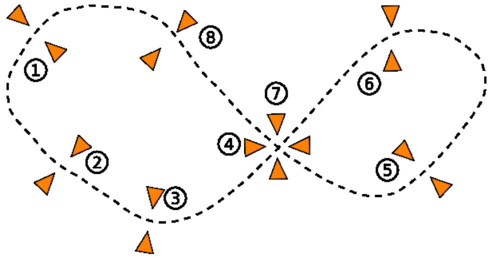
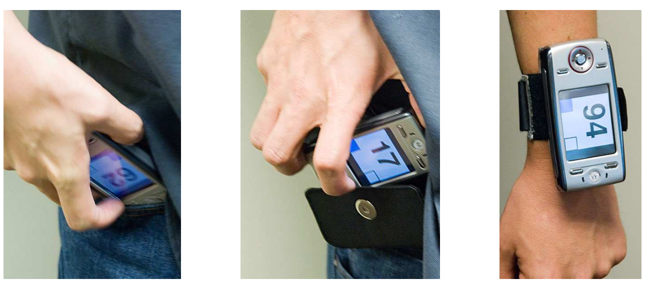


Figure 1. The path participants walked, starting at flag 1 and proceeding either clockwise or counterclockwise.

because walking is in general a head-up task (that is, people usually look ahead some distance while walking rather than looking directly at the floor). The walking direction was counterbalanced between clockwise and counter-clockwise directions.

For the device placement condition, we instructed participants to put the phone into a pants or skirt pocket (after removing other items), into the manufacturer-provided holster clipped to the top of the pants or to the belt, or to attach it to the wrist with a velcro strap (Figure 2). While using an actual touchscreen watch for the wrist condition—such as SMS Technology's M500—would have allowed for a more natural experience, we opted instead to maintain internal validity by using the same device (and therefore retaining the same display and touch input properties) for all three conditions.



(a) (b) (c)

Figure 2. Placement: pocket (a), hip (b), and wrist (c).

To determine the amount of time required to access the phone, we asked each participant to perform a simple task. Periodically, the phone generated an alert in the form of a sound and vibration. Each participant was requested to respond to these alerts as quickly as possible. When the alert occurred, the participant retrieved the device and looked at the screen, which showed a blue box and a large number (Figure 3(a)). The participant made a mental note of the number on the display and slid the blue box to the right to unlock the phone. The participant then chose the number they had just seen from a list of four numbers (Figure 3(b)). After choosing the number, the participant returned the phone to its original position and waited for the next alert.

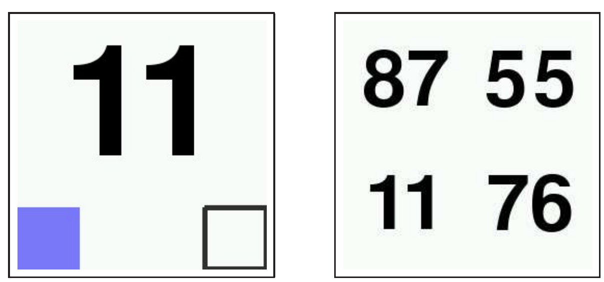
Software and Equipment

The software for our study was implemented in Python on a Motorola E680i cameraphone running the GNU/Linux operating system. The E680i has a 320x240 color touchscreen, stereo speakers, and a number of buttons. For this study, we used only the touchscreen and deactivated all of the hardware buttons so they would not be pushed accidentally.

During each condition, the operation of the software was the same. At random intervals between 20 and 40 seconds (selected from a uniform random distribution), the software generated alerts. An alert consisted of a loud mobile phone ringing sound and vibration that lasted up to 20 seconds. During the alert the software also displayed the prompt number and unlock mechanism on screen (Figure 3(a)).

To respond to the alert, participants first unlocked the phone. Unlocking was accomplished by sliding the blue box to the right edge of the screen (similar to the Apple iPhone unlock gesture). This mechanism was implemented to prevent accidental responses while retrieving the phone from the pocket or holster. Next the phone displayed a screen consisting of a two by two grid of numbers (Figure 3(b)). The software waited for the user to select a number and logged the response. This interaction emulated common interruptions on mobile devices (for example: receiving a call, reading the caller ID, and sending the caller to voicemail). At this point the trial was complete. The phone relocked itself, and a timer was set to generate the next alert. The software logged the timestamps of each alert, the movements of the slider, and the selection of the numbers.

Because the phone was unable to report whether it was in a pocket or holster, we implemented an extremely simple light sensor using the built-in camera. Approximately four times per second, the pixel values from the camera were summed and stored. With the assumption that the holster and participants' pockets would be dark, we could detect when the phone was removed from, and replaced in, the pocket or holster. Figure 4 shows the output of the light sensor and other events logged by the software.



(a) (b)

Figure 3. Screen (a) is shown when an alert occurs. The participant must mentally note the displayed number and slide the blue box from the left to the target box on the right. Screen (b) is shown after the slide is completed; from the displayed four numbers, the participant must touch the number that was displayed on screen (a).

Dependent Measures

We are most interested in how device placement and mobility influences access time—the amount of time it takes for a participant to retrieve the device and respond to an alert.

Figure 4 shows a timeline of a typical notification-response cycle. The points in the timeline are as follows:

1. Blank screen; participant walking track or standing.
2. Alarm starts ringing.
3. Participant pulls phone from pocket or out of holster. Light level increases to nearly 100%.
4. Participant starts to move slider.
5. Screen with four numbers is displayed.
6. Participant has picked a number; screen returns to blank.
7. Participant returns phone to pocket or holster. Light level falls to 0%.

We extracted several measurements from the timeline (numbers refer to the timeline in Figure 4):

- *Access time*: Alarm start (2) to user acknowledgment of the alarm by moving the slider (4).
- *Pocket time*: Alarm start (2) to retrieval of the device from the pocket or holster (3) (does not apply to wrist).
- *Hand time*: End of phone removal from the pocket or holster (3) to the beginning of participant's response (4) (does not apply to wrist).
- *Slide time*: Moving the slider (4 to start of 5).
- *Answer time*: Picking a number from the set of four (5).
- *Replacement time*: Replacing the phone to the pocket or holster (start of 6 to 7—does not apply to wrist).

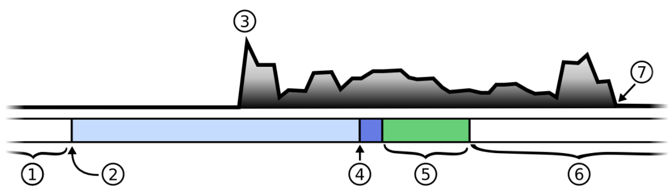


Figure 4. Timeline of events and status of brightness detector during one notification-response cycle. The top line is the percentage of light detected from the camera (complete darkness, 0% on the bottom), and the bottom is the timeline of events recorded by the phone's logging software.

We define access time in this context as the time required for the participant to react to the alarm, acquire the device (either looking at the wrist or pulling it from a pocket or the holster), note the number on the screen, and touch the slider.

Procedure

The evaluation for each participant began with the researcher presenting an overview of the study. Participants completed a consent form and a short survey about their use of mobile technology. The researcher then explained the experimental software and tasks. Each participant practiced responding to alerts three times on the phone for each of the placement conditions (pocket, hip, wrist) resulting in a total of nine practice responses. Next, the researcher familiarized the participant with the track by walking it twice in each direction; on the first lap the participant followed the researcher, while on the second, the researcher followed the participant. Finally, the researcher answered any questions from the participant, and started data collection.

Each condition consisted of a set of trials. The number of trials per condition was either five or seven, averaging to six per condition per participant. This design was selected to prevent participants from anticipating the end of a set of trials. For the walking conditions, participants were told they could slow down or stop if needed to respond to the alert quickly, but to keep walking if possible.

After the completion of the required number of trials, the phone displayed "STOP" in a large font on the screen. Participants were requested to stop where they were (if in the mobile condition) to allow the researcher to measure how far they had walked around the track.

Participants

We recruited fifteen participants (5 females) for our study from our academic institution. The average participant age was 24.87 years ($SD = 2.99$). Fourteen of our participants were right handed. Each of our participants owned a mobile phone and all but three had that phone with them on arrival. Six of our participants wore a wristwatch when they arrived to participate in the study. We also asked about several other devices and where the participants carried them. Table 1 provides a summary.

	Pocket	Bag	Hip	Body	*Total*
Mobile phone	7	4	1	—	12
Phone headset	4	—	—	—	4
Audio player	4	5	1	1	11
Camera	6	5	—	1	12
Total	21	14	2	2	39

Table 1. Devices carried by participants and their location. "Body" refers to on-body placement of a device, "bag" includes purses and backpacks.

RESULTS

One participant was discarded as an outlier—having taken up to 8.5 standard deviations longer than average to respond to alerts—leaving 14 participants. Each participant performed all six of the conditions. Each condition averaged six alerts per condition, for a total of 504 alert-response cycles. For this paper, we consider $p < .05$ to be significant and will only report p values for non-significant results.

A multi-way ANOVA reveals that the placement of the de-

	Placement	Walking	Standing	*Average*
Access Time	Hip	5.377 (.947)	5.660 (1.155)	5.518 (1.047)
	Pocket	4.414 (.904)	4.817 (.875)	4.616 (.897)
	Wrist	2.728 (.291)	2.846 (.420)	2.787 (.360)
Pocket Time	Hip	4.355 (.906)	4.312 (.770)	4.333 (.836)
	Pocket	3.427 (.770)	3.829 (.788)	3.625 (.868)
Hand Time	Hip	1.047 (.656)	1.339 (.728)	1.199 (.707)
	Pocket	1.109 (.647)	1.093 (.396)	1.092 (.536)

Table 2. Statistics for mean (SD) hand, pocket and access times in seconds.

vice has a significant effect on *access time* (Table 2), but mobility is not significant ($p = .14$). There is also no significant interaction between mobility and placement ($p = .81$). *Post-hoc* analysis of the access times for the placement variable using a paired Student's T-test reveals a significant difference between all three combinations of variables: hip/pocket, hip/wrist and pocket/wrist. Therefore, we have a total ordering of access time for the placement condition: wrist ($M = 2.8s$) $<$ pocket ($M = 4.6s$) $<$ hip ($M = 5.5s$); by comparing the mean access times, we can see that the pocket condition yields a 66% longer access time than the wrist while the hip requires 98% more access time than the wrist.

For non-watch conditions, where the light sensor was used, *pocket time* (Table 2) was significantly affected by placement, but not mobility ($p = .128$), and there was a significant interaction between placement and mobility. There was no significant effect of placement for *hand time* ($M = 1.145$, $SD = .628$), but there was a significant effect for mobility as well as an interaction.

Some, although not all, of the other measures described earlier were significant (refer to Figure 4). The *answer time* was found to be significantly affected by mobility, but not placement (walking: $M = 1.227$, $SD = .304$; standing: $M = 1.479$, $SD = .583$). Measures non-significantly impacted by placement or mobility were *slide time* ($M = .071$, $SD = .72$) and *replacement time* ($M = 3.195$, $SD = 1.787$). Finally, participants on average selected the correct number 89.3% of the time; this was not found to be significantly affected by any of the conditions.

DISCUSSION

The watch placement condition resulted in much faster access to the device. This finding is unsurprising, because participants did not have to remove the phone from the pocket or holster in order to use it.

In Figure 4, *access time* (from 2 to 4 in the timeline) is divided into two segments for non-wrist conditions: *pocket time* (from 2 to 3) and *hand time* (from 3 to 4). The statistics in Table 2 reveal that the majority of access time is consumed by pocket time [2]: on average, 78% of the time from the alarm until the participant started moving the slider was involved in getting the device out of the pocket or holster!

The watch condition also resulted in much more *consistent* access time to the device; the standard deviation of access time for the pocket and hip conditions is 2.5 and 2.9 times more than the wrist condition, respectively. The long time required to retrieve the phone from its holder may help explain why the participants in the Cui *et al.* study reported missing phone calls due to how they carried their phones [2].

While we anticipated the superior performance of the watch condition, we did not expect the holster to perform *worse* than the pocket condition for access time. Reviewing user comments made during the study, however, it becomes clear that poor holster design may account for this result. Despite our use of the manufacturer's holster, several participants complained during practice trials that the holster was difficult to use, and that difficulty may have persisted through the course of the study. An additional possibility is familiarity; while participants were presumably well-practiced with putting items into and removing them from the pockets of their own pants, none of the participants reported using a holster to carry their phone (Table 1) and therefore may have been slower with the holster than would have otherwise been expected. Given these factors, our results for the hip condition should probably be viewed as a worst case for holster access.

Finally, it was interesting to find that, in contrast to previous work [5], walking did not significantly impede user performance relative to standing still. In contrast, our data was trending to show that standing resulted in slower access. One possible explanation for this difference is our inability to separate reaction time and access time with our current experimental design. It is possible that the walking conditions are keeping the participants more engaged in the experiment relative to the standing conditions, and therefore the reaction time is slower while standing. More work is needed to confirm this hypothesis.

[2]Note that in Table 2 $pocket + hand \neq access$. Two participants had light sensor problems, making hand and pocket time impossible to recover. Thus, these subjects were not included in this subsection of the table, making the quantities not exactly sum.

CONCLUSIONS

Our study helps quantify the impact of mobility and on-body placement of a device on the user's ability to respond to alerts. We found that placing a device in a pocket or holster incurs a large time penalty when it comes to accessing the device—up to 78% of the total reaction time, while a wrist-mounted device allowed for consistently faster access. The results of the study suggest that distributing functionality across on-body devices can be done in such a way to minimize access time while the user is on the go.

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